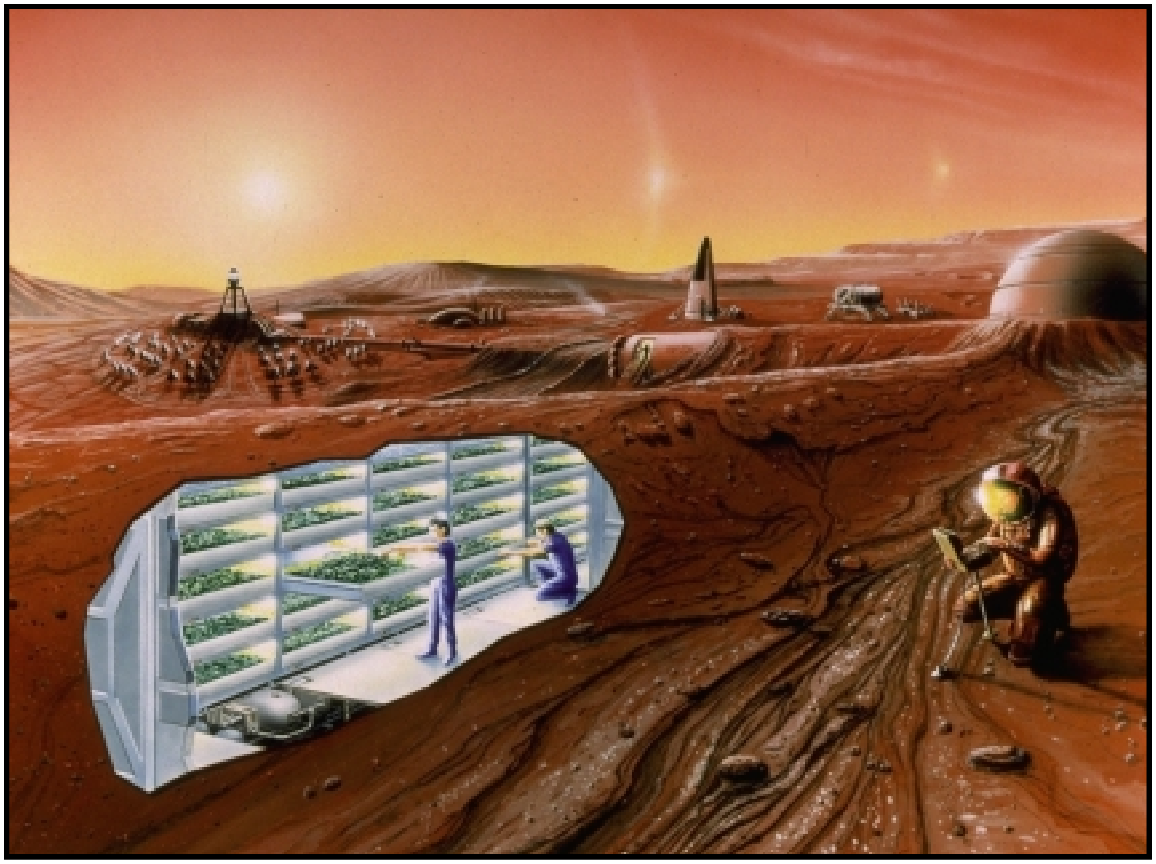

Astrobiology Technology Branch (SSR) Overview

The Astrobiology Technology Branch supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding life in the universe. Current branch efforts encompass research and technology development for advanced life support, utilization of planetary resources, and astrobiology. Advanced Life Support focused research is directed primarily at physicochemical processes for use in regenerative life support systems required for future human missions and includes atmosphere revitalization, water recovery, waste processing / resource recovery, and systems modeling, analysis and controls associated with integrated subsystems operation. In-Situ Resource Utilization (ISRU) technologies will become increasingly important on every Mars lander between 2003 and a human mission to Mars. The branch focus is on the development of technologies for Mars atmosphere acquisition, buffer gas production, and CO_2 compression. Research and technology development for astrobiology includes understanding the physical and chemical limits to which life has adapted on Earth, the molecular adaptations that have allowed living systems to inhabit extreme environments, and the application of this knowledge to biotechnology, nanotechnology, and planetary protection. Researchers in the branch also develop flight experiments and associated hardware for shuttle, ISS, and unmanned NASA missions.

Mark H. Kliss

Chief, Astrobiology Technology Branch (SSR)

DYNAMIC MODELING OF LIFE SUPPORT SYSTEMS

C. Finn and H. Jones

Dynamic system models have been developed which track the flow of material through a regenerative life support system over time-periods of months to years. These models are being used to help evaluate system design and operation issues for the Advanced Life Support Systems Integrated Test Bed (ALSSITB). The model captures the main flow stream characteristics associated with atmosphere regeneration, water recovery, crop growth, food processing, and waste processing. The system simulation quantifies the variations in stream flow rates and subsystem processing rates so that estimates can be made on buffer requirements for various system configurations and design options. It is also being used to investigate scheduling, operations, and control issues.

Dynamic modeling is an important tool for developing robust system designs. Static or steady state models are often used to obtain estimates on nominal processor flow rates and re-supply requirements. However, more detailed system design requires information on processor operation ranges and system buffer requirements, which are a function of the system dynamics and control strategy. In general, the level of model complexity needed increases throughout the system design cycle. In the early design phase, simple dynamic models provide useful information for estimating the processing rates and storage sizes needed to meet all of the system performance specifications. More complex models are needed for the design of control systems, the development of failure recovery approaches, and planning how to add redundancy to the system in order to improve system safety and reliability.

A top-level dynamic system model of the ALSSITB has been developed at Ames Research Center to investigate system design issues. The ALSSITB is currently being developed by Johnson Space Center to support long-duration human testing of integrated life support systems. It is comprised of a set of interconnected test chambers with a sealed internal environment capable of supporting a four-person test crew for periods exceeding one year. The life support systems to be tested will consist of both biological and physical/chemical technologies that perform air revitalization, water recovery, biomass production, food processing, and solid waste processing. A variety of system designs for the ALSSITB have been studied to date.

Each system design is described in terms of the set of technologies used, the configuration of the technologies in the system, and the manner in which the system is operated. The overall technology set available for consideration includes technologies that provide various levels of regeneration. For example, life support consumables can either be supplied or produced, and waste products can either be processed, dumped, or stored. An optimal system generally consists of some combination of re-supply, *in situ* resource utilization, venting, dumping, and material recycling using physical/chemical or biological processors. System configuration refers to the manner in which the processors are connected for a given set of technologies. For example, there are multiple flow paths possible and various options for the placement and sizing of buffers. System operation strategies need to be investigated, since some system components can be operated in a number of ways. Some technologies can be operated in either batch mode or continuous mode. For batch operation, the batch sizes and operation schedule can vary. For continuous operation, processing rates can be either constant or variable, and the operational parameters, control objectives and constraints can vary.

Among the ALSSITB designs simulated thus far are systems with different air revitalization systems using various circulation patterns, technology sets and operational strategies. For each system design that was simulated, the results were compared with those of a baseline. This enabled an evaluation of how well each system met performance criteria, by maintaining controlled atmospheres, adequate reserves, etc., and to determine the required capacity for the various processors and storage. ❑

SOLID-STATE COMPRESSORS FOR MARS ISRU

J. Finn, L. Mulloth, and B. Borchers

One important way to extend the science and exploration capabilities of Mars surface missions is to use the readily available Mars atmosphere as a resource to provide critical supplies that would otherwise limit the mission or make it too expensive. Compressed and purified gases, oxygen, important chemicals, and even rover and rocket fuel can be manufactured largely from martian atmospheric gases. This would save the cost of their transport from Earth and ensure that a mission doesn't end when it 'runs out of gas.' These techniques are examples of a popular mission strategy that is generally termed *In Situ* Resource Utilization (ISRU).

The Mars atmosphere consists mostly of carbon dioxide, with relatively small amounts of nitrogen and other gases. At about 0.7 kilo-Pascals (0.1 pounds per square inch) total pressure, the mixed gases are too thin to be useful directly, and so the atmospheric constituents must be separated from each other and compressed. NASA Ames Research Center is developing solid-state adsorption compression and separation technology to acquire the Mars atmospheric constituents and make them available for downstream processing or direct use.

The Ames adsorption compression technology uses a zeolite adsorbent bed that can adsorb large quantities of carbon dioxide at the ambient temperature and pressure of the Mars surface. Its capacity for the other Mars gases is much lower; these gases are drawn through the adsorbent and stored in a second bed for later processing. When the adsorbent is saturated with carbon dioxide, the compressor is isolated and warmed. Carbon dioxide then evolves from the sorbent, resulting in a rapid pressure increase inside the compressor. When the pressure reaches a desired level, the carbon dioxide can be drawn off. The supplied pressure is easily regulated by controlling the power level of the compressor's heater. When the supply of carbon dioxide is exhausted, the bed is allowed to cool and to adsorb another load of carbon dioxide. The cycle can be repeated indefinitely.

The first uses for this adsorption compression technology will be on robotic exploration missions. A prototype for adsorption compression at this mission scale is shown in Figure 9. The one-kilogram device shown has been tested successfully under simulated Mars surface conditions. Under these conditions, it produces approximately 15 grams of carbon dioxide per day at a pressure of 120 kilo-Pascals (17.4 pounds per square inch), and requires an average of seven watts of power during five hours of production. Larger scale productions will be more economical as the fraction of structural mass decreases; in this case, the anticipated daily production level would be about 250 grams carbon dioxide per kilogram of compressor mass. ❑

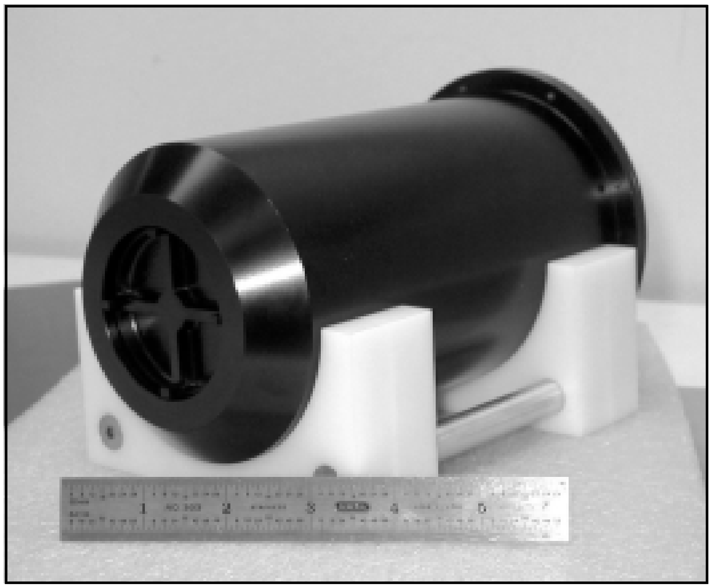

Figure 9: Prototype solid-state adsorption compressor for Mars carbon dioxide, 15 grams/day scale. A nitrogen-argon mixture is produced as a by-product.

ACTIVATED CARBON FROM INEDIBLE BIOMASS

J. Fisher and S. Pisharody

As manned missions become longer, re-supply of life support materials becomes increasingly more difficult and expensive. The expense of re-supply can be avoided by regenerating life support materials. Bioregeneration involves the use of plants to grow food, but plants generate a large amount of inedible biomass, which must be recycled. Incineration is one of the most promising technologies for recycling wastes such as inedible biomass. Unfortunately, inherent to the process of incineration is the formation of undesirable byproducts such as nitric oxide (NO) and sulfur oxides $(SO)_x$. Conventional incineration technologies treat off-gases, such as NO_x and SO_x, by using selective catalytic reduction processes, but these technologies require the injection of expendables such as ammonia to treat the NO_x. Activated carbon can also be used to remove NO_x and SO_x via the process of adsorption.

The Solid Waste Resource Recovery project group is investigating unique ways to use crop wastes to make activated carbon. This would eliminate the need for expendables in the flue gas cleanup during long duration, manned, space missions. It may be possible to make this activated carbon from the inedible biomass available from growing plants in space. Over forty crops are being considered for food production, which will to provide the nutritional needs of crews on long missions. One or more of these plants may be a good raw material for making activated carbon.

The flow diagram (see Figure 10), shows the planned role of the activated carbon as part of the incineration process for resource recovery. The contaminants in the flue gas are adsorbed on activated carbon at room temperature. In a regeneration process at high temperatures, the adsorbed NO_x is reduced by the carbon forming N_2 and CO_2. The off-gases formed during the activation process are directed back into the incinerator. After several regenerations, the spent carbon is mixed with the incinerator feed and is converted to CO_2 and H_2O in the incinerator. Thus, contaminants are removed without the need for re-supply.

The challenge is to make quality activated carbon. Quality activated carbon is a highly porous, carbonaceous material. The porous structure is controlled by the nature of the starting material and the process used for carbonization and activation. Conversion of inedible biomass to activated carbon and the use of activated carbon to convert adsorbed NO_x to N_2 gas, has been successfully demonstrated at Ames Research Center. There is an excellent chance that this research will result in a process that will one day be used to manufacture activated carbon in space for use in the life support system. ❑

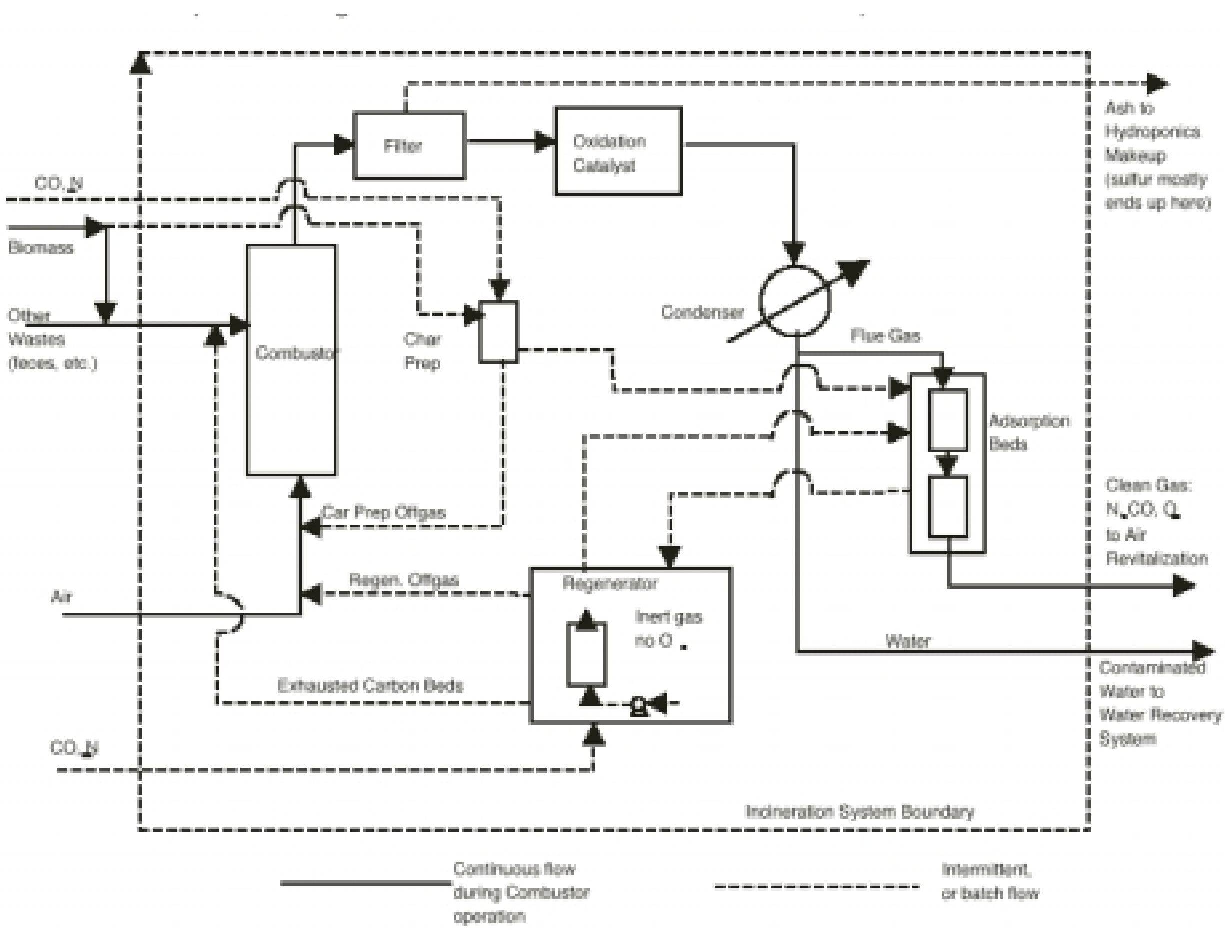

Figure 10: Flow diagram of reactive carbon for flue gas cleanup.

DEVELOPMENT OF THE VAPOR PHASE CATALYTIC AMMONIA REMOVAL PROCESS

M. Flynn and B. Borchers

Ames Research Center has recently completed the development and testing of a prototype Vapor Phase Catalytic Ammonia Removal (VPCAR) system. The VPCAR technology represents the next generation in space flight water recovery systems. Water is the single largest re-supply requirement associated with human space flight, accounting for 87% by mass of an astronaut's daily metabolic requirement. The VPCAR system achieves a mass metric almost an order of magnitude better than the current state of the art water processors. (Mass metric is a technique used to reduce all performance parameters into launch mass.) Incorporating the VPCAR technology into human space flight missions could potentially save hundreds of millions of dollars in re-supply costs, depending on the specific mission scenario. As a result, a human-rated version of the VPCAR technology has been authorized for development, and when completed it will be used for human testing in a closed chamber.

The VPCAR process is a two-step distillation based water processor. The current configuration of the technology is shown in Figure 11. The VPCAR process is characterized by the use of a wiped-film rotating-disk (WFRD) vacuum evaporator to volatilize water, small molecular weight organics, and ammonia. This vapor stream is then oxidized in a vapor phase catalytic reactor to destroy any contaminants. The VPCAR process uses two catalytic beds to oxidize contaminants and decompose any nitrous oxide produced in the first bed. The first catalytic bed oxidizes organics to carbon dioxide and water, and ammonia to nitrous oxide and water. This oxidation reactor contains 1% platinum on alumina pellets and operates at about 523 K. The second catalytic bed reduces the nitrous oxide to nitrogen and oxygen. This reduction catalyst contains 0.5% ruthenium on alumina pellets and operates at about 723 K. The reactor and distillation functions occur in a single modular process step. No scheduled maintenance is required. The system has no re-supply requirements. The process achieves between 97-98% water recovery.

The VPCAR activity is significant in that it represents the development of the next generation of life support water recovery technology. It also provides an excellent example of how the research and development capabilities of one NASA Center can be integrated into the operational requirements of another NASA Center to reduce the cost of human space flight programs. Ames Research Center's involvement has spanned from the first principle definition to the model development, bench scale and lab scale prototype development, and contract management of the development of a human-rated version of the technology for transfer to a NASA space flight center. Development of the final space flight version will be the responsibility of Johnson Space Center. ❑

Figure 11: Vapor Phase Catalytic Ammonia Removal (VPCAR) water recycling system.

SEARCH FOR THE UPPER TEMPERATURE LIMIT OF MULTICELLULAR ORGANISMS NOT SEEN BY TRADITIONAL ENVIRONMENTAL RESEARCHERS (‘MONSTERS’)

J. Trent

Until fairly recently it was widely believed that the highest temperature to which life on Earth could possibly adapt was around 60°C. Above this temperature, it was assumed, essential biomolecules would be destroyed, and life of any kind would therefore also be destroyed. In the last two decades, however, this assumption has proved to be wrong. Many new species of bacteria and archaea have been discovered in a wide range of habitats that have ambient temperatures well above 60°C. These heat-loving organisms, known as ‘thermophiles,’ are thriving in thermal hot springs around the world. The hottest of them are living in submarine hot springs that may reach temperatures of 113°C (hydrostatic pressure prevents boiling). The discovery of these hyper-thermophilic microbes has had important scientific and practical consequences. Scientifically, it has expanded our knowledge of the diversity of organisms on Earth, and it has provided important insights into mechanisms for thermo-stabilization of essential biomolecules. This information is of interest to NASA’s Astrobiology program goals of “establishing the limits for life in environments that provide analogues for conditions on other worlds” and “how life evolves on the molecular, organismic, and ecosystem levels.”

While many new species of hyperthermophilic bacteria and archaea have been discovered in the last 20 years, few species of thermophilic Eukarya were discovered. Eukarya is one of the three major branches on the tree of life and includes all of the more familiar life forms (Figure 12). For Eukarya the upper temperature limit remains around 60°C, set by some species of fungi found living in self-heating compost piles. Figure 13 shows the current estimates for the temperature range in the universe, the range in which life as we know it exists, and the ranges to which each of the three major divisions of life have adapted. It is not yet clear, however, if the unimpressive upper temperature limits of Eukarya reflects an inability of these organisms to adapt to high temperature habitats or our inability to find Eukarya living in these habitats. Our scientific objective was to answer the fundamental question: what is the upper temperature limits for macroscopic Eukarya on Earth?

To answer this question, researchers at Ames used small, robust, submersible video cameras and lighting system to hunt for macroscopic Eukarya in the hot springs of Yellowstone National Park. The temperatures of these springs ranged in from 31°C to 120°C. It seems likely that there are many undiscovered thermophilic Eukarya lurking in the depths of these hot springs. NASA’s video system, like other NASA systems probing distant planets, allows observations in otherwise inaccessible habitats. To date, Eukarya have been observed in springs up to 40°C, but the search goes on at higher temperatures. Ultimately thermophilic Eukarya will be trapped and brought under scrutiny in the laboratory. It seems likely that new species of extremely thermophilic Eukarya will reveal molecular adaptations to high temperatures that have not been observed in the microbial systems currently being investigated. Such adaptations will expand our view of how complex organisms cope with extreme environments and provide insights into what kinds of organisms may inhabit the hypothetical hydrothermal communities in the subsurface on Mars or the oceans of Europa. For Astrobiology, the search for thermophilic Eukarya will provide guidance for search strategies for life elsewhere in the universe and their discovery here will raise some intriguing possibilities for finding complex life in hydrothermal systems beyond Earth. ❑

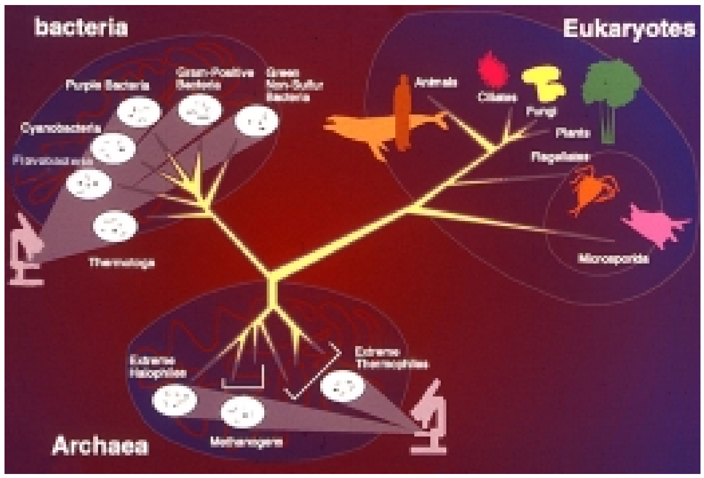

Figure 12: A stylized representation of the three groups that make up the 'tree' of life, indicating the differences in cell types (background), and showing that bacteria and archaea are microscopic single-celled organisms (balloons), while most Eukarya are macroscopic multicellular organisms. NB: bacteria and archaea used to be classified together as 'prokaryotes' based on structural features of their cells, but recent analyses of critical biomolecules indicates that dividing prokaryotes into two separate groups gives a more accurate representation of phylogeny. By both cell structure and molecular criteria, bacteria and archaea are distinct from Eukarya.

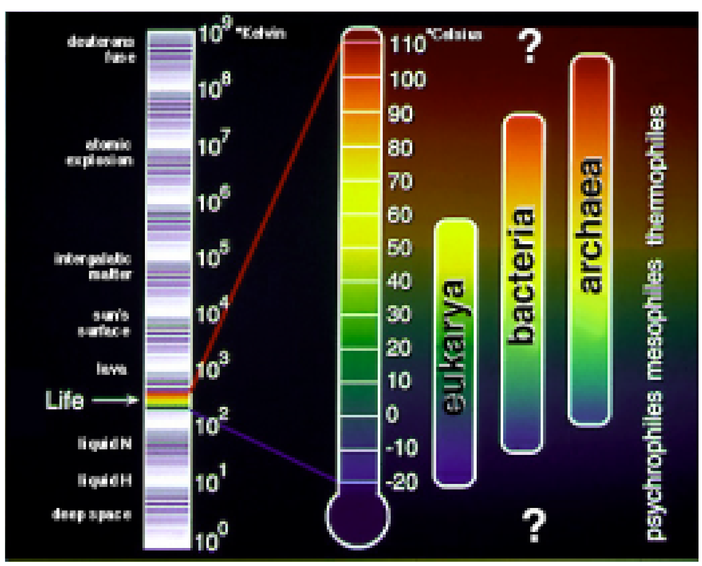

Figure 13: The temperature range in the universe (°K), the temperature range for life and for the three major divisions of life (°C) – Eukarya, bacteria, and archaea. The characterization of organisms based on temperature ranges for optimum growth (psychrophiles <15°C; mesophiles 15-50 °C; and thermophiles >50°C) are indicated to the right. The question marks indicate that we do not yet know the upper temperature limits for any the three divisions of life.